Flow Characteristics on Shared Hiking/Biking/Jogging Trails

Mark R. Virkler and Rajesh Balasubramanian

Many localities have provided trails shared by hikers, bicyclists, and joggers. Some of these trails serve significant transportation purposes while others are overwhelmingly devoted to recreational use. In either case, these facilities present the unusual traffic flow situation of a facility serving three classes of users with distinctly different flow characteristics. The interactions between these three user groups are addressed in here.

Information on shared trail volumes is given in the next section, followed by a brief review of quality of flow descriptions for facilities serving only the pedestrian or bicycle modes. A procedure developed by Botma (*1*) to describe quality of flow on shared pedestrian/bicycle paths is then presented.

Data from two trails, one in Missouri and another in Australia, were collected to provide some understanding of the three types of users and interactions between the three groups. The data are used:

1. To describe the flow characteristics on these shared hiking/bicycling (biking)/jogging trails.

2. To describe the frequency of desired overtakings (passes) and potential conflicts on trails used by hikers, bicyclists, and joggers.

3. To compare estimates of desired overtakings and potential conflicts to measured values of overtaking frequency and delayed overtakings.

The results are used to indicate the potential accuracy of the Botma level of service measures for these types of facilities.

BACKGROUND

Volumes on Shared Trails

Data on traffic volumes for multiple use trails are scarce. Hunter and Huang (*2*), as part of the National Walking and Bicycling Study, described usage of both exclusive bicycle facilities and multiple use paths (e.g., hikers, bicyclists, and joggers) in the U. S. In a summary table for multiple use paths, 13 sites in seven states were described. On bridges, volumes ranged from a low of 400/day (with 78% bicyclists and 22% walkers or joggers) on the 14th St. Bridge in Washington, D.C. to a high of 2871 (41% bicyclists) over 12 hours on the Brooklyn Bridge. On trails, annual volumes ranged from 135,000 (65% bicyclists) to 400,000 (20% bicyclists).

The same study described hourly usage over 12 hours from one site in Raleigh, North Carolina. Hourly volumes ranged from approximately 0 to 14 for joggers, 18 to 60 for bicyclists, and 38 to 100 for pedestrians.

A study of a pedestrian/bicycle path in Brisbane, Australia reported a 15-hour count near the CBD. The 15-hour total was 1919, including 848 pedestrians and 1071 bicyclists. The morning peak hour had 162 bikes and 72 pedestrians with a 74/26 directional split. The evening peak hour included 152 bikes and 135 pedestrians with a 62/38 directional split (Brisbane City Council Department of Development and Planning, unpublished data).

Describing Quality of Flow

Pedestrian Facilities

Level of Service (LOS) for exclusive pedestrian facilities is defined by the Highway Capacity Manual (*3*) for both walkways and queuing areas. In both cases, LOS is determined by average pedestrian space (sq.m./ped.).

For a pedestrian walkway, LOS B requires 4.0 sq. m. of space for each pedestrian. Capacity operation occurs at the minimum space for LOS E (0.6 sq. m. per pedestrian). It appears obvious that if mounted bicyclists were present in a traffic stream, the space available even within a good pedestrian LOS, such as LOS B, would be inadequate for bicycle operation.

Bicycle Facilities

Botma (*1*) described the Dutch guideline (*4*) for the required width of a separate bicycle path and determination of LOS for bicycle facilities. Hindrance, which relates to the frequency of overtaking and meeting maneuvers, determines LOS.

Hindrance is described as the percent of bicyclists that are hindered over a 1 km travel distance. The amount of hindrance depends upon the type of maneuver (e.g., meeting or overtaking) and the space available for the maneuver (i.e., the path width). Hindrance scoring was based upon perceived hindrance derived from user surveys. An overtaking counts as one hindrance and a meeting of a traveller in the opposite direction counts as one-half of a hindrance.

When speed is normally distributed, desired overtaking frequency can be found from Wardrop's formulation (*5*):

$$F = Q^2\sigma/[U\sqrt{\pi}] \qquad (1)$$

where:

F = frequency of desired overtakings
Q = one-way flow rate
σ = standard deviation of speed (0.83 m/s in the Dutch manual)
U = space mean speed (5.0 m/s in the Dutch manual)

The result is referred to as "desired" overtakings because the effect of oncoming traffic, which could delay passes is not considered. When oncoming traffic is light, one might expect most desired overtakings to be completed. When oncoming traffic is heavy, few desired overtakings would be completed.

The number of meetings is determined by fundamental flow parameters (5):

$$N_{meet} = X\ T\ Q_1\ Q_2\ (1/U_1 + 1/U_2) \qquad (2)$$

where:

N_{meet} = total number of meetings for all users over length X and time T
X = length of site
T = time period considered
Q_1 = flow in direction 1
Q_2 = flow in direction 2
U_1 = speed in direction 1
U_2 = speed in direction 2

Botma also described quality of flow in terms of Mean Time Between Events (MTBE). Events are maneuvers (passings or meetings). MTBE is the reciprocal of the frequency of events.

Shared Pedestrian/Bicycle Facilities

Botma (*1*) extended the concept of MTBE on bicycle facilities by adding in the effect of pedestrians within the traffic stream. This first led to a recommendation for LOS criteria for one-way pedestrian-bicycle paths.

One-way Paths. Pedestrians are assumed to seldom overtake other pedestrians. Therefore pedestrian LOS is determined by the frequency with which an average pedestrian would be overtaken by bicyclists. The total number of overtakings of the slower pedestrians by faster bicyclists can be determined by (*5*):

$$N_{f/s} = X\ T\ Q_f\ Q_s\ (1/U_s - 1/U_f) \qquad (3)$$

where:

$N_{f/s}$ = total number of overtaking of slower units by faster units
(e.g., overtakings per km per hr)

X = length of site
T = time period considered
Q_f = flow of faster group in subject direction
Q_s = flow of slower group in subject direction
U_f = mean speed of faster group
U_s = mean speed of slower group

The frequency with which an average pedestrian will be overtaken by bicyclists can be derived from Equation 3.

Ignoring bicycles passing bicycles, bicycle LOS was taken to depend upon the frequency with which an average bicyclist would overtake pedestrians (which can also be derived from Equation 3). Botma then used an average pedestrian speed of 1.25 m/s and average bicycle speed of 5 m/s to develop tables of service flow rates for both pedestrians and bicyclists.

Two-way Paths. For two-way shared paths Botma assumed that both overtakings and meetings would affect LOS (with an overtaking again equal to one event and a meeting equal to one-half of an event). For pedestrians, LOS was based upon meetings and overtakings by bicycles (and not other pedestrians). For bicyclists, LOS was based upon meetings and overtakings involving both pedestrians and bicycles.

The results presented by Botma relied on the above assumed speeds for bicycles and pedestrians and an assumed standard deviation of speed (0.83 m/s) for bicyclists. In discussing the results, Botma emphasized the importance of:

- collecting additional field data to better understand the distributions of speeds within the user groups,
- determining the time required to complete overtaking maneuvers, and
- understanding second order interactions (e.g., when an meeting would occur during an overtaking maneuver).

The field study results described below address these three concerns.

FIELD STUDY

The study site in Missouri was the MKT Trail, a former railroad spur, now a recreational “hiking/biking trail” in Columbia, Missouri. The trail is level and straight and has a crushed rock surface with an average width of about 3 m. The surface wearing pattern indicates that users generally treat the trail as having one lane for each direction. This pattern of usage was confirmed by observation. The center of each “lane” has a firm surface for bicycle tires. The middle of the trail and the outside edges have significant amounts of loose gravel that bicyclists usually avoid. When bicyclists or joggers pass other users, they generally leave their own lane and complete the pass by traveling in the opposing lane. Individual walkers and joggers generally remain in the middle of each “lane” but will share the lane when traveling in pairs, resulting in each person encountering a somewhat rougher surface. The portion of the trail studied is close to the most popular access point near Stadium Blvd.

The Australian site is in Brisbane, paralleling the Brisbane River. The portion of the trail studied is straight and level with a smooth asphalt surface. A painted center line divides the 2.9 m wide path. Like the Columbia trail, the Brisbane trail generally operates as two one-way lanes. The portion of the trail studied is close to the Queensland University of Technology, the city CBD, and the city’s botanical gardens.

Data Collection

An observer with a stop watch collected data to describe the following traffic flow characteristics.

1. Average speed and speed distributions for each mode along a short (8 to 16 m) section.
2. Time required to pass other users.

3. Passing maneuvers over a significant length (275 m) during 15 minute increments (in Brisbane)
4. Delayed passes over the same extended length during 15 minute increments (in Brisbane)

In Columbia the data were collected on pleasant autumn weekend days when recreational usage was expected to be high. In Brisbane the data were collected on pleasant Tuesdays between noon and 2 p.m. when users appeared to be primarily university student bicycle commuters and lunch hour exercisers who were jogging or walking.

Speed and Overtaking Time

The flow characteristics of the two sites are summarized in the following tables. Table 1 shows the characteristics of the speed distributions for the three user groups. The Columbia speeds were measured over 9 m and the Brisbane data over 8 m. For both sites, the mean jogger speed was almost twice the mean hiker speed and the mean bicyclist (biker) speed was nearly twice the mean jogger speed. Among the three groups, the coefficient of variation (standard deviation divided by mean) was highest for bikers at both sites. The most striking difference between the two sites was in jogging speed. Compared to Columbia, the Brisbane joggers had higher mean speeds but a much lower standard deviation of speed. Each of the individual speed distributions appeared to be close to bell shaped but the "all" category had distinct peaks for each of the three types of traffic.

Table 1 Speed Distributions of Each Group (m/s)

Speed Statistics	Hikers	Joggers	Bikers	All
		Columbia		
Mean	1.59	2.87	5.95	3.39
Median	1.63	3.05	6.00	2.80
Standard Deviation	0.28	0.79	2.10	2.25
Coeff. of Variation	0.18	0.27	0.35	0.66
Minimum	0.92	1.08	1.23	0.92
Maximum	2.09	4.24	10.21	10.21
Count	40	33	35	108
		Brisbane		
Mean	1.56	3.34	5.76	3.16
Median	1.60	3.32	5.80	3.01
Standard Deviation	0.24	0.44	1.33	1.79
Coeff. of Variation	0.15	0.13	0.23	0.57
Minimum	0.82	2.19	2.03	0.82
Maximum	2.17	4.79	9.88	9.88
Count	187	151	105	443

The time required for one individual to pass another is shown in Tables 2 and 3. The time to pass was measured by an observer with a stopwatch. The pass began when the passer left the right side lane (left side in Brisbane) and ended when the passer re-entered that lane. Data were collected under light flow conditions and no passes "hurried" due to oncoming traffic were included.

For simplicity in comparisons, Table 2 shows only the mean time to pass. One might assume that the faster the passer compared to the passed, the less the time required to pass. This assumption was upheld in Brisbane. In Columbia it was upheld when a hiker was being passed by any of the three groups. However, a Columbia biker passing another biker required less time than a biker passing a jogger or a hiker. A Columbia jogger took less time to pass another jogger than to pass a hiker.

Table 2 Mean Time to Pass (seconds) for Each Combination

	Hiker passed	Jogger passed	Biker passed
	Columbia		
Hiker passes	17.3	-	-
Jogger passes	6.1	4.4	-
Biker passes	3.9	6.5	3.7
	Brisbane		
Hiker passes	9.68	-	-
Jogger passes	2.78	3.67	-
Biker passes	1.86	2.05	2.63

Table 3 describes some of the characteristics of the passing time data. The Brisbane passing time averages were uniformly shorter than those for Columbia. The coefficients of variation in Brisbane were uniformly larger than those for Columbia.

Table 3 Distributions of Time to Pass (seconds) for Each Combination

	Columbia					
Passing Statistics	H / H	J / H*	B / H	J / J	B / J	B / B
Mean	17.3	6.1	3.9	4.4	6.5	3.7
Median	16.8	5.7	3.6	4.3	6.4	3.6
Standard Deviation	4.3	1.7	1.3	0.5	1.2	1.3
Coeff. of Variation	0.25	0.28	0.32	0.11	0.19	0.35
Minimum	10.6	3.6	1.8	3.6	4.8	2.2
Maximum	24.9	8.2	6.0	5.0	8.2	5.6
Count	8	7	11	5	9	9
	Brisbane					
Mean	9.7	2.8	1.9	3.7	2.1	2.6
Median	7.8	2.4	1.7	2.6	1.9	1.9
Standard Deviation	5.1	1.4	0.94	3.5	0.74	2.0
Coeff. of Variation	0.52	0.50	0.50	0.96	0.36	0.75
Minimum	4.8	1.1	0.53	1.0	0.98	0.91
Maximum	19.5	8.4	5.2	12.1	4.1	5.5
Count	7	82	82	8	22	5

* The notation with the slash denotes who overtakes whom (e.g., J/H means jogger overtakes hiker).

Overtakings

Equation 1 was used to predict overtaking demand within groups (e.g., bikers passing bikers) and Equation 3 was used to predict overtaking demand between groups (e.g., bikers passing joggers) during the sixteen 15 minute time intervals studied in Brisbane. During those intervals bicycle volumes ranged from 1 to 16 with a mean of 5.9, jogger volumes ranged from 1 to 13 with a mean of 8.6, and hiker volumes ranged from 4 to 30 with a mean of 12.6. Table 4 shows a comparison of the total number of overtakings to those predicted by the theory expressed in the two equations. Hikers overtaking other hikers and joggers overtaking hikers were overpredicted. However the predicted values of the other four types of overtakings seem fairly close to the observed values.

Table 4: Comparison of Theoretical Overtaking Demand to Observed Overtakings

	B/B	J/J	H/H	B/J	B/H	J/H	Sum
Theory	6.6	9.5	60.6	28.6	161.1	166.2	432.6
Actual	8	10	11	33	140	92	294

Figure 1 shows a comparison of actual overtakings to those predicted for each of the 16 time intervals. The correlation coefficient, r, was 0.79.

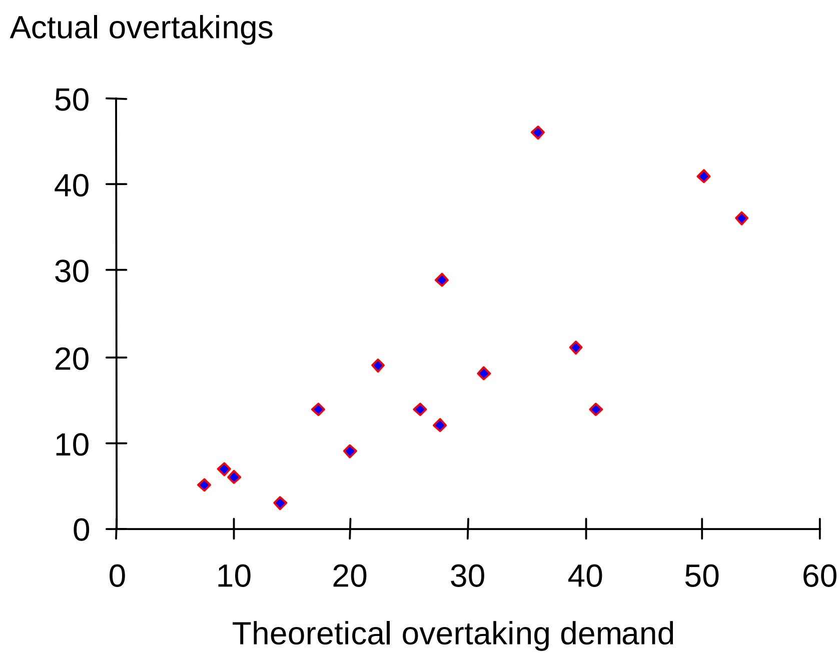

Figure 1: Actual vs. Theoretical Overtakings

Delayed Overtakings

A formulation adapted from work by Glennon for passing conflicts on two-lane highways was used to predict potential conflicts, which would be expected to lead to delayed overtakings (*6*). The probability of an oncoming vehicle being in conflict with an overtaking vehicle is based on Poisson (random) arrivals of vehicles at a point. The probability of a conflict increases with the flow rate from the opposing direction and the time period required to complete the overtaking.

$$P(A) = 1 - P(0) = 1 - e^{-Vt/3600} \tag{4}$$

where:

- $P(A)$ = probability of a passing vehicle encountering a conflict
- $P(0)$ = probability of a passing vehicle encountering no opposing vehicles
- V = flow rate from opposing direction (veh/hr)
- t = time period in which opposing vehicle which would pass a particular point could cause a conflict (sec)
- 3600 = number of seconds in an hour

The time t was based upon the premise that no conflicting traffic should occupy the space to be used by the passer during the overtaking maneuver. This calculation involved the time required for the passing maneuver from Table 2 and the speeds from Table 1. For each of the six types of passes, P(0) was determined separately for each potential type of conflicting traffic (hiker, biker, or jogger). The probability of no conflicts for each type of passer was then derived from the probability of no conflicting bike, no conflicting jogger, and no conflicting hiker. For example, for a biker to pass a jogger during one 15 minute increment, the probabilities of no oncoming bikers, joggers, or hikers were 0.986, 0.946, and 0.918 respectively. The probability of no conflicting traffic when a biker wished to pass a jogger was therefore 0.986 x 0.946 x 0.918 = 0.856. The probability of a conflict (when a biker wished to pass a jogger during that 15 minute interval) was 1 - 0.856 = 0.144 or 14.4%. The probabilities of conflicts during the 16 measurement periods are summarized in Table 5.

Table 5: Probabilities of Passing Conflicts During 15-Minute Intervals (%)

	B/B	J/J	H/H	B/J	B/H	J/H
mean	23.8	23.4	38.0	19.2	17.6	18.3
maximum	36.9	35.4	53.1	30.1	27.8	28.2
minimum	12.2	12.2	21.9	9.6	8.8	9.4

Table 6 shows the results for the 16 observation periods. As was the situation with passing demand, hikers passing hikers and joggers passing hikers were cases of overprediction. This could be expected because the theoretical overtaking conflicts equalled the number of desired overtakings multiplied by the probability of a conflict.

Also once again, the other four types of overtakings appear to be predicted reasonably well.

Table 6: Comparison of Theoretical Overtaking Conflicts to Delayed Passes Observed

	B/B	J/J	H/H	B/J	B/H	J/H	Sum
Theory	1.7	2.0	23.0	5.4	30.5	28.8	91.4
Actual	4	2	0	7	34	5	52

Figure 2 shows a comparison of delayed passes to predicted conflicts for each of the 16 time intervals. The correlation coefficient, r, was 0.82.

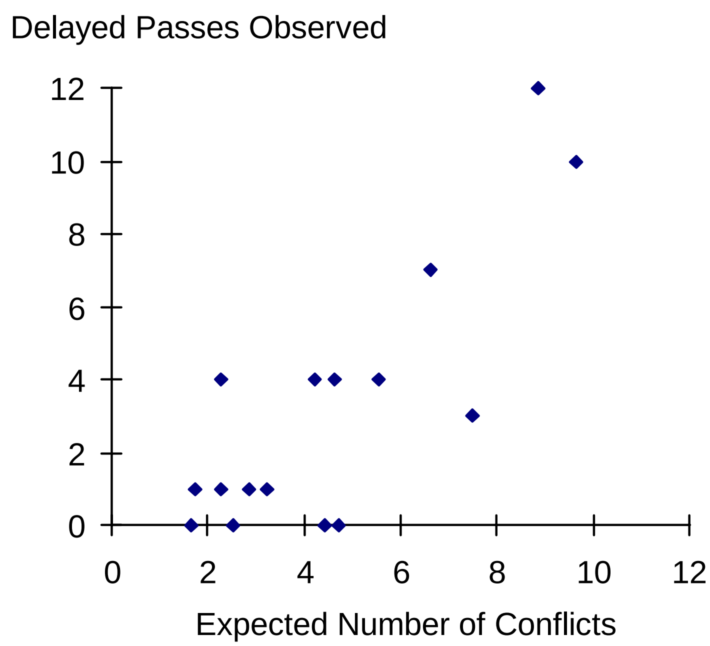

Figure 2: Delayed Passes vs. Expected Conflicts

CONCLUSIONS

The objectives of the field study were to describe trail flow characteristics and to compare estimates of desired overtakings and potential conflicts to measured values of overtaking frequency and delayed overtakings. In comparing the two trails, mean speeds of the three types of traffic were fairly close to each other, but the standard deviation of jogger and biker speeds were much higher in Columbia. The recorded biking speeds of 5.95 and 5.76 m/s were somewhat higher than the that used in the Dutch manual (5.0 m/s). The standard deviations of biking speeds (2.10 m/s in Columbia and 1.33 m/s in Brisbane) were much higher than the standard deviation of biking speeds used in the Dutch manual (0.83). Passing demand within a group such as bicycles is directly proportional to the standard deviation of speed and inversely proportional to mean speed. Therefore, the Dutch manual yields higher allowable volumes for a given LOS than would be the case if speed characteristics like those in Columbia and Brisbane were used.

In general, the equations to predict passing demand performed reasonably well. Estimates of hikers passing hikers and joggers passing hikers were high when compared to the observed values, but the other four estimates were quite close. Thus the results tend to support the framework developed by Botma for bikers passing bikers and bikers passing pedestrians. Interestingly, Botma assumes that pedestrians seldom overtake other pedestrians and therefore does not include these overtakings in his approach. The low number of these overtakings in the data tend to indicate that that this assumption may not be inappropriate.

Estimates of the probabilities of overtaking conflicts ranged from 9.4% to 38% for the study periods. Estimates of passing conflicts for hikers passing hikers and joggers passing hikers were high when compared to the observed values of delayed passes. Since the actual number of passes for these two cases were much lower than predicted, one could expect that the estimates of passing conflicts would also be high. The estimates of passing conflicts for the other four passing conditions appeared to be reasonably close to the number of observed delayed passes.

The Botma approach was the only found in the literature to predict flow characteristics on shared use trails. The results indicate that the Botma approach yields reasonable results for the range of flow conditions studied here. The two trails in this study had significantly higher standard deviations of biking speeds compared to that used by Botma. If one uses measured speed characteristics, the approach used to predict passing demand should yield accurate results.

The Columbia trail was primarily recreational and unpaved while the Brisbane trail served both recreational and commuting purposes. It is expected that other trails may serve much different mixes of trip purposes and might therefore exhibit significantly different speed and overtaking characteristics. For that reason, much could be learned from a more thorough study of other trails with different mixes of trip purposes. The authors understand that some paved trails have significant use by in-line skaters. A more comprehensive study could address the impact of this fourth mode upon shared trail operation.

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REFERENCES

1. Botma, Hein. 'Methods to Determine Level Of Service for Bicycle Paths and Pedestrian Bicycle Paths' *Transportation Research Record 1502*, 1995. pp 38-44.

2. Hunter, William and Herman Huang. “User Counts on Bicycle Lanes and Multi-Use Trails in the United States.” Transportation Research Record 1502, 1995.

3. *Highway Capacity Manual*, TRB Special Report 209. TRB, Washington, D.C., 1994.

4. 'Sign up for the bike. Design manual for a cycle-friendly infrastructure'. Record 10 of CROW, Ede (NL), 1993.

5. Wardrop, J. G. Some Theoretical Aspects of Road Traffic Research. Proceedings of the Institute of Civil Engineers, Vol. 12, Part 2, London, June 1952, pp. 333-334.

6. Glennon, J. NCHRP Report 214: *Design and Traffic Control Guidelines for Low-Volume Rural Roads.* Transportation Research Board, Washington, D. C., Oct. 1979, Appendix F.